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Review on treatment of industrial wastewaters by Electrochemical Coagulation (ECC)

Neshma C M
neshmagowda2456@gmail.com
JSS Science and Technology University, Mysore, Karnataka

Dr. B. M. Krishna
bmkrishna_71@yahoo.com
JSS Science and Technology University, Mysore, Karnataka

ABSTRACT

Electrochemical coagulation (ECC) technology has a long history and is still a very active location for research until today. The environmental sector showing large interest in ECC because of increasing pollution in different types of industrial effluent. It also contributions to the electrode material, operating condition, and reactor design. The electrocoagulation applications, advantages, and disadvantages discussed here. The goal is to form flocks of metal hydroxides among the effluent to be cleansed by electro-dissolution of soluble anodes. ECC was found to be capable of removing COD & Color from the affluent & it was found that the totally different electrode has different effectiveness in removing COD & Color, depends on the type of electrode. Finally, electrocoagulation can be the good option for the treatment of wastewater from various industries.

Keywords**—** *Electrochemical coagulation (ECC), Electrochemical reactor (ECR), Operational factors, Industrial wastewater*

1. INTRODUCTION

Industrial Wastewater treatment is one of the significant challenging tasks in the 21st Century due to the blooming of miscellaneous industry such as food industry effluent, textile industry effluent, Pulp and paper industry effluent, tannery effluent etc., which generates the large amount of effluent Piya - Areetham et al., (2006). In the past few years, ECC has been used for the treatment of water containing oil effluent, foodstuff effluent, dyes, suspended particles, chemical & mechanical polishing effluent, organic matter from landfill leachates, de-fluorination of H_2O, artificial detergent effluent, mine effluent and high - grade metal-containing the solution. Water is virtually vital to all living things on this planet. While nature has the remarkable capability to cope up with little amounts of aqua wastes and pollution, it'd have an affects if we have a tendency to didn't treat the billions of gallons of industrial effluent produced each day before releasing it back to the environment. Effluent treatment facilities help to scale back of pollutants in wastewater.

Electrocoagulation (ECC) incorporates a long history. The primary plant was inbuilt in London by Vik et al., 1889 for the treatment of sewerage treatment plant engineered and electrochemical treatment has been used via a combination of the domestic wastewater with saline (Sea) water Kabdasl et al., (2012). ECC System is existing for several years (Dietrich patented, 1906) mistreatment form of anode and cathode geometries. In United state 1909, J.T. Harries awarded a patent for sewer water treatment by electrolysis using sacrificial aluminum and iron anodes. ECC, the passing of electrical current through water, has verified very effective within the removal of contaminants from water. ECC has become one among the reasonable effluent treatment process around the world by reducing electricity consumption and miniaturization of the required power provides. Al and Fe electrode is commonly used and its varied benefits on their accessibility, i.e. abundance on the world and low value, non-toxicity etc., Anode and cathode are usually made of the same metal, though electro dissolution occurred solely at the anode. Depending on pH, it spontaneously undergoes hydrolysis in water.

The treated effluent has several benefits over alternative sources of water like, it minimizes pollution, augments groundwater resources by artificial recharge and it's a decent nutrient source for landscape and farm irrigation Saleem et al., (2000). According to Rajeshwar et al., (1994) there are three benefits of using electrochemical techniques include environmental compatibility, skillfulness, energy potency, safety, property, flexibility to automation, and value effectiveness.

2. PRINCIPLES AND FUNDAMENTALS OF ELECTROCOAGULATION

Electrocoagulation technology may be a treatment method of applying electric current to treat and flocculate contaminants while not having to add coagulations. Shammas et al., (2010) declared that once current being applied coagulation occurs, capable of removing little particles since DC applied, settling them into motion. Electrochemical coagulation (ECC) may be a broad-spectrum treatment technology that removes total suspended solids (TSS), serious metals, blended oils, bacterium and other contaminants from H_2O. In an electrocoagulation process consists of three consecutive steps.

(i) Formation of coagulant by electrolytic oxidization of the sacrificial anode
(ii) Destabilization of the contaminants, emulsion breaking & particulate suspension
(iii) Aggregation of the destabilized phases to flocs kind.

An EC reactor is created of an electrolytic cell with one anode and one cathode Immersed in an electrolyte, as shown in Figure 1. Once connected to an external power supply, the anode material can electrochemically corrode due to oxidation, whereas the cathode is going to be subjected to passivation.

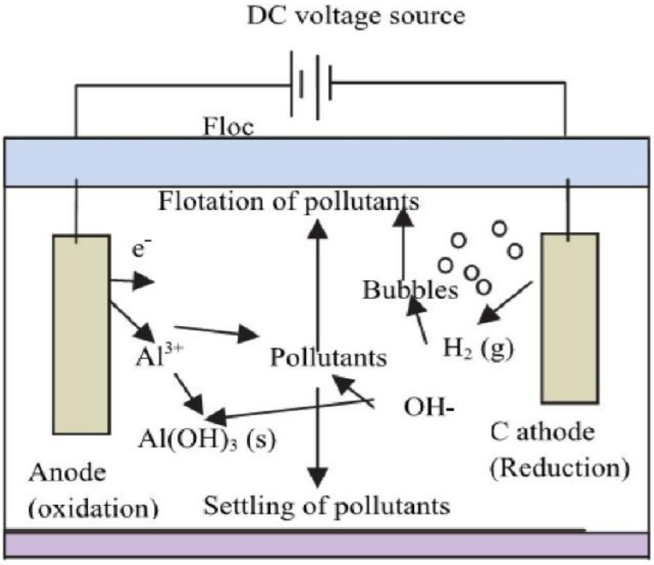

Fig. 1: Schematic diagram of an electrochemical cell Essadki et al., (2012)

An external voltage is applied between the plates via an external circuit, completing the path for current to flow in the system as follows an electron leaves the negative terminal of the power supply and moves to the cathode, where a charge transfer reaction occurs between the electron and a molecule on the cathode surface. This reaction produces a negatively charged ion which crosses the electrolyte to the anode. At the anode, a second charge transfer reaction transfers the electron to the anode and it moves through the external circuit to the positive terminal of the power supply. Therefore, an electric current flows through the external circuit from the cathode to the anode and ionic current flows through the electrolyte from the anode to the cathode. The technique depends on the electrochemical dissolution of sacrificial Al or Fe electrodes. The generated cations contribute by decreasing the stability of the suspended entities, by decreasing their zeta potential. Also, upon formation of hydroxide ions at the cathode, metal ions complex with iron or aluminum hydroxides, which are known to be efficient coagulants. The hydrogen bubbles formed at the cathode adsorb the flocs formed from the process and ensure their flotation, which simplest their separation from the treated water (Zongo et al., 2009). The most commonly used electrode materials in the electrocoagulation process are aluminum & iron, sometimes steel. Krishna et al, (2010).

The following physiochemical reactions while taking place in the EC cell (Paul et al., 1996).

- Electroflotation of the coagulated particles by O_2 and H_2 bubbles made at the electrodes.
- Cathodic reduction of impurities present in wastewater.
- Discharge and coagulation of colloidal particles.
- Electrophoretic migration of the ions in resolution.
- Reduction of metal ions at the cathode.
- Other electrochemical and chemical processes.

In AN EC experiment, the electrode assembly is typically connected to an external DC supply. Consistent with (Mollah et al., 2001) ECC efficiency is powerfully associated with the dissolution of the electrode also the quantity of metal dissolved or deposited depends on the amount of electricity passed through the electrolytic solution (Paul et al., 1996).

If during this method M is taken into account as an anode, the subsequent reaction will take place as:

At anode:

$$M_{(s)} \rightarrow M^{n+}{}_{(aq)} + n\,e^{-} \quad (1)$$

$$2H_2O \rightarrow 4H^{+}{}_{(g)} + O_{2\,(g)} + 4e^{-} \quad (2)$$

At cathode:

$$M^{n+}{}_{(aq)} + n\,e^{-} \rightarrow M_{(s)} \quad (3)$$

$$2H_2O + 2e^{-} \rightarrow H_{2\,(g)} + 2OH \quad (4)$$

If iron and iron electrode, aluminum and the aluminum electrode, and also iron and aluminum electrodes were used, the generated $Fe_{(aq)}^{3+}$ and $Al_{(aq)}^{3+}$ are produced. After metal reaction with iron and aluminum, hydroxyl ions will produce metal hydroxides or poly-hydroxides (Ramesh et al., 2007). For instance, aluminum in water produces $\left[Al\left(H_2O\right)_6\right]^{3+}$, $\left[Al\left(H_2O\right)_5 OH\right]^{2+}$, $\left[Al\left(H_2O\right)_4 OH\right]^{1+}$ or monomer or polymer strains of $\left[Al\left(OH\right)_2\right]^{+}$, $\left[Al\left(OH\right)\right]^{2+}$, $\left[Al_2\left(OH\right)_2\right]^{4+}$, $\left[Al_6\left(OH\right)_{15}\right]^{3+}$, $\left[Al_{13}\left(OH\right)_{34}\right]^{5+}$, over a period of duration pH can wide range. Similarly, ferric ions produced by electrochemical oxidation of iron electrode may form $Fe\left(OH\right)_3$ monomer and polymeric hydroxyl complexes specifically $Fe\left(H_2O\right)_6^{\ 3+}$, $Fe\left(H_2O\right)_5\left(OH\right)^{2+}$, $Fe\left(H_2O\right)_4\left(OH\right)_2^{\ +}$, $Fe_2\left(H_2O\right)_8\left(OH\right)_2^{\ 4+}$ and $Fe_2\left(H_2O\right)_6\left(OH\right)_4^{\ 4+}$ rely on the liquid medium of pH scale. These compounds increase the elimination efficiency (Bazrafshan and Mahvi, 2007; Jiang et al., 2002; Druiche et al., 2008; Kim et al., 2007 ;). This Aluminum - hydroxides compounds have an expanded surface area as a coagulant that is helpful for a fast adsorption of soluble organic compounds and metal ions (Daneshvar et al., 2006). Since $Al\ \left(OH\right)_3$ has higher weight and density, it settles quicker (Malakootian, et al., 2009) and it's easier to form the trapped colloidal separate from the liquid medium by deposit or H_2 flotation (Kobya et al., 2006).

Several distinct electrochemical processes occur throughout the electrocoagulation process independently.
The process occurring is Seeding, Emulsion Breaking, Halogen Completing, Bleaching, electron flooding & oxidation and reduction reaction.

- **Seeding:** Anode reduction of metal ions take places that become new centers for larger, stable, insoluble complexes.
- **Emulsion Breaking:** Water insoluble material formed by oxygen and hydrogen ions reacting with emulsified substances.
- **Halogen Completing:** As the metal ion bind themselves to halogens resulting in the formation of large insoluble complexes and isolating pesticides, herbicides, chlorination PCBs, etc.
- **Bleaching:** By oxygen species produced in the reaction chamber and providing oxidization of chemical substances and also reducing bio-hazards through oxidization of bacteria, viruses, etc.
- **Electron flooding:** Allowing colloidal material to precipitate, water affects the polarity of water. The electrons create osmotic pressure rupturing cell walls of bacteria, cysts, and viruses.
- **Oxidation and reduction reactions:** are forced to their natural end point. Electrocoagulation can speed up the natural processes occurring in wet chemistry.

3. THE POTENTIAL USE OF ELECTROCOAGULATION FOR INDUSTRIAL WASTEWATER

3.1 Tannery and Textile Industry Effluent

Tannery and textile wastewater represent a vital economic sector in several countries. A large amount of effluent from tannery and textile industry wastewater become an environmental problem. Tannery wastewater & textile wastewater will cause severe environmental issues associated with its high chemical oxygen demand, high biochemical oxygen demand, rich content of total suspended solids, and oil and grease contents beside with the elevated chromium concentration and objectionable It's, therefore, necessary to treat effluent wastewater discharging into the receiving water bodies. By using Electrocoagulation, COD, BOD & color remove effectively

Kongjao, et al., (2008), investigated on electrocoagulation method was distributed to at the same time take away chromium and numerous pollutants from tannery effluent at a close temperature within the laboratory scale. Cheap-cost commercial iron plates were utilized during this study as anodes and cathode materials. Effects of assorted parameters were investigated together with varieties of electrode configuration, initial pH of wastewater (7–9), current density (15.7–24.6 A/m^2) and the current rate of flow effluent (0–3.67 $lmin^{-1}$). The optimum condition was found by applying the monopolar electrode during parallel association at the current density of 22.4 A/m^2, the flow rate of wastewater of 3.67 $lmin^{-1}$ and 20 min electrolysis time. The initial pH of effluent ranging from 7–9 provided the similar removal potency. In optimum condition, over than 95% of Cr and pollutants except TKN and TDS were eliminated from the effluent and therefore the properties of the treated effluent met the quality and permissible to discharge into the environment. The required energy consumption at optimum condition was less than 0.13 $kWhm^{-3}$ wastewater. In addition, the COD reduction was fit very well with the first-order kinetics model.

Banhadji et al. (2010), worked on the coincident removal of organic and inorganic pollutants from tannery effluent. During this work, aluminum was chosen as an anode while the iron was not used because it results in a black coloration of the liquor that became dark quickly. Aluminum used as a result of it needless oxidation potential. The results show Al cathode, a current density of 75 A/m^2 in 45 minutes is that the optimum condition for removing pollutants from tannery effluent. In optimum condition, were quite over 90% of COD, BOD_5, turbidity, iron, Cr, and NO3- were removed. The main aim of NO3- removal by electrocoagulation method is Al oxidation at the anode that may decompose and scale back NO3- from the water.

Merzouk et al. (2010), worked on a Synthetic solution and textile wastewater. Electrocoagulation and electroflotation unit of a capacity 1.5 L electrochemical reactor. Was parameter consists of Temperature 40°C, pH 7 to 6, conductivity 2.1 µS/cm, current density 11.55 A/m^2, the 1.5L capacity of the reactor? Aluminum electrodes used for both anode and cathode with dimensions of 27 mm x 17 mm x 1 mm, SA – 4.59 cm^2. Electrode gap, 1-3 cm, pH varied up to 4-9, current density 11.55 - 91.5 A/m^2, stirring speed 200 – 1000 rpm, Temperature 25 – 60°C, ET 120 mins, samples collected at 10 mins interval. COD 79.7%, BOD: 88.9%, & Color removal ranged from 93% and energy consumption ranged from 4 to 29 kWh/m^3 depending on different operating conditions. Decolorization and COD removal raised by raising in time, current density and rpm.

Merzouk et al. (2009), investigated on Textile dye wastewater. Consists of Batch electrocoagulation process reactor, pH - 7.8, Color – Red Dye concentration 200 mg/L, COD – 2,500 mg/L, Electrode used were Aluminum used as both anode and cathode with dimensions of 240 mm x 20 mm x 1 mm, SA – 48 cm^2. Electrode gap consists of 10 mm. Total volume 8.6 L, pH varied up to

4.1 – 9, and Current density varied up to 20.83 to 62.5 A/m^2. Samples collected at every 10 mins interval. Color removal 78 to 93%, COD reduction 80%, and Energy consumption ranged to 4 to 29 kWh/m^3 depending on different operating conditions COD and color removal was influenced by initial concentration, and pH and current density.

Shivaprasad et al., (2017) investigated on Electrocoagulation technique by using Copper, Iron and Aluminum electrodes for the treatment of textile effluent. The batch electrocoagulation was evaluated for color, COD and BOD reduction and therefore the operating parameters like contact time and voltage were studied. The Effluent was treated at 4V, 8V and 12V time taken is 50 minutes using three different electrode materials and samples were collected every 10 minutes. From the results Iron electrode is found efficient for textile industry wastewater treatment at 12V and contact time of 30 minutes, the pH was 8 and the spacing between electrodes was 3cm. It was observed that COD and Colour were degraded from an initial concentration of 6000 mg/L and 2868 mg/L to 620 mg/L and 104 mg/L severally. Iron electrode removal potency of 89% for COD, 96% for color. Compared to Aluminum and Copper electrodes, Iron electrode gives more efficiency in degradation of pollutants. For Iron Electrode 12V, 30 minutes and the 3cm gap is found to be the optimum values to achieve a higher removal efficiency of pollutants. The treated wastewater was clear and post-treatment is required to meet discharge limit of COD.

A Study has been conducted on the treatment of effluent from a tannery plant and textile plant using electrocoagulation technique. The wastewater consists of high initial pollutant parameter level mentioned seeing table 1.

Table 1: Effect of inter electrodes distance and electrolysis time on pollutant removal efficiency in the ECC process

S. no.	Sample	Experimental Setup	Optimum parameters	Initial concentration In mg/L	Removal Efficiency %	Reference
1	**Industrial Textile wastewater**	**Sample volume:** 2200ml **Electrode material:** Iron **Electrode arrangement:** batch reactor **No of electrode:** 2	**Inter electrode distance:** 20mm **Current density:** 8 A/m^2 **Electrolysis time:** 70 min. **pH:** 7	COD-1260 Turbidity-1310 NTU TS- 1750	COD-70 Turbidity-90 TS-50	**Zodi et al., (2010)**
2	**Tannery wastewater**	**Sample volume:** 800ml **Electrode material: Iron** Al/Fe **Electrode arrangement:** continuous reactor **No of electrode:** 2	**Inter electrode distance:** 20mm **Current density:** 20 A/m^2 **Electrolysis time:** 240 min. **pH:** 6-7	COD 3200 BOD 1250 TDS 6700 CHROMIUM 40	BOD-35 TDS-42 COD-42 Cr – 46	**Babu et al. (2007)**
3	**Tannery wastewater**	**Sample volume:** 1000ml **Electrode material:** Al **Electrode arrangement:** Batch reactor **No of electrode:** 2	**Inter electrode distance:** 10mm **Current density:** 4.96 A/m^2 **Electrolysis time:** 90 min. **pH:** 3-7	COD-2566 BOD-960 Turbidity-314	COD-49.8 BOD-84.4 Turbidity-69.7	**Xiangdong li et al., (2011)**
4	**Tannery wastewater**	**Sample volume:** 400ml **Electrode material:** Al **Electrode arrangement:** Batch reactor **No of electrode:** 4	**Inter electrode distance:** 10mm **Current density:** 22.7 A/m^2 **Electrolysis time:** 60 min. **pH:** 6	COD-20440 TSS-11500	COD-49 TSS-42	**Durmaz et al., (2017)**
5	**Tannery wastewater**	**Sample volume:** 400ml **Electrode material:** Iron **Electrode arrangement:** Batch reactor **No of electrode:** 2	**Inter electrode distance:** 60mm **Current density:** 33.3 A/m^2 **Electrolysis time:** 30 min **pH:**7.4	COD-3700 Sulfide-440	COD-56 Sulfide-97	**Apaydin et al., (2009)**

3.2 Food industry effluent

Wastewater from agro-industries come back from a myriad of the source and their composition varied greatly. However, it is characterized by high BOD & high COD because of their high level of organic content.

Table 2: Outline of recent application of ECC within the treatment of food industry effluent as explained below

S. no	Sample	Experimental Setup	Optimum parameters	Initial concentration in mg/L	Removal Efficiency %	Reference
1	**Dairy wastewater**	**Sample volume: 1500ml** **Electrode material: Iron** **Electrode arrangement: Batch reactor** **No of electrode:2**	**Inter electrode distance: 10mm** **Current density:** 27 A/m^2 **Electrolysis time: 50min** **pH:6.3 – 6.8**	COD: 3900 Turbidity:1744 NTU TS: 3090 TN:113	COD:70 Turbidity: 100 TS:48 TN:93	**Kushwaha et al., (2010)**
2	**Baker's Yeast wastewater**	**Sample volume: 800ml** **Electrode material: Iron & Aluminium** **Electrode arrangement: Batch reactor** **No of electrode: 4**	**Inter electrode distance: 20mm** **Current density: 7** A/m^2 **Electrolysis time:** 50 min. **pH:5.5-6.5**	COD:2485 TOC:1061 Turbidity: 2075 NTU	COD:71-69 TOC:53-52 Turbidity: 90-56	**Kobya & delipinar (2010)**
3	**Coffee wastewater**	**Sample volume: 600ml** **Electrode material:** Al **Electrode arrangement: Batch reactor** **No of electrode: 2**	**Inter electrode distance: 10mm** **Current density: 20** A/m^2 **Electrolysis time:** 105 min. **pH:5-7**	COD 26240	COD- 95	**Asha et al., (2015)**
4	**Coffee wastewater**	**Sample volume: 4000ml** **Electrode material:** Al **Electrode arrangement: Batch reactor** **No of electrode: 2**	**Inter electrode distance: 15mm** **Current density: 10.83** A/m^2 **Electrolysis time:** 10 min. **pH:7**	COD 2820	COD- 90	**Ha Manh Bui (2017)**
5	**Coffee wastewater**	**Sample volume: 1000ml** **Electrode material:** Al & Fe **Electrode arrangement: Batch reactor** **No of electrode: 2**	**Inter electrode distance: 10mm** **Current density: 17.34** A/m^2 **Electrolysis time:** 120 min. **pH:7**	COD-12840	COD- 89	**Asha et al., (2016)**
6	**Egg processing wastewater**	**Sample volume: 1000ml** **Electrode material:** Al, Fe or SS **Electrode arrangement: Batch reactor** **No of electrode: 2**	**Interelectrode distance: 70mm** **Current density: 15** A/m^2 **Electrolysis time:** 35 min. **pH:4.5**	COD-8983 TSS-1651 Turbidity-2060	COD-97 TSS-97 Turidity-99	**Xu et al., (2002)**
7	**Tea factory wastewater**	**Sample volume: 400ml** **Electrode material:** Steel **Electrode arrangement: Batch reactor** **No of electrode: 2**	**Interelectrode distance: 5mm** **Current density:** 24V **Electrolysis time:** 90 min. **pH:6**	COD-607 BOD-193 Colour-9210Pt/Co	COD-96.6 BOD-84 Colour-99	**Mghanga et al. (2009)**

8	Potato chips manufacturing wastewater	**Sample volume: 250ml** **Electrode material:** Al & Fe **Electrode arrangement: Batch reactor** **No of electrode: 4**	**Inter electrode distance: 40mm** **Current density:** 20 A/m^2 **Electrolysis time:** 40 min. **pH:4-6**	COD-2800 Turbidity- 610 NTU	COD-60 Turbidity-98	**Kobya et al, (2006)**
9	Pasta and cookie processing wastewater	**Sample volume: 1500ml** **Electrode material:** Al **Electrode arrangement: Batch reactor** **No of electrode: 8**	**Inter electrode distance: 10mm** **Current density: 18.2** A/m^2 **Electrolysis time:** 60 min. **pH:4**	COD-7500 BOD-3445 Colour-35Pt/Co Turbidity-1153	COD-90 BOD-96 Colour-57 Turbidity-97	**Roa-Morales et al (2007)**

4. KEY PARAMETERS INFLUENCING ELECTROCOAGULATION

4.1 Effect of applied current density

Current density is one among the necessary factors influencing the electrocoagulation method because it determines both the rate of electrochemical metal dosing to the effluents and therefore the electrolytic bubble density production **(**Holt. et al, 2006) for the given time, the pollutant removal potency increased considerably with the rise in current density. Applied current density plays a major role in electrocoagulation method for effluent treatment and pollutants removal because it is that the most operational parameter that may be easily controlled within at intervals the treatment process and directly leading to additional efficient and quick removal. Moreover, bubble size decreases with increasing current density that is helpful to the separation method.

Increase in current density results as a rise in temperature. The rise of current density with temperature was attributed to the raised activity of destruction of the aluminum oxide film on the electrode surface. When the temperature is just too high, there's a shrink of the big pores of the $Al(OH)_3$ get leading to additional compact flocs that are additional possible to deposit on the surface of the electrode. Though higher temperature provides a better conductivity, therefore, a lower energy consumption. color and COD removal, it seems that for a given retention time, inter-electrode distance and pH of the solution have an effect on pollutant removal efficiency because it raised with the rise in current density, the treatment potency was primarily suffering from charge loading; high current densities, the extent of anodic dissolution raised and successively the quantity of hydroxo-cationic complexes leading to increasing of the colour and COD removal

The color reduction raised with rising in current density. This could be explained by the discharge of metal ions increasing with an electrical potential. Therefore, there's a rise in floccule production and therefore an improvement within the color removal potency.

4.2 Effect of voltage

Voltage is one of the vital factors influencing the electrocoagulation method. Voltage is directly proportional to the current density. Voltage will increases pollutant removal potency and electrode dissolution as well increase.

4.3 Effect of pH

Electrocoagulation pH is a very important parameter that influences the performance of the EC method. If the pH will increase with an increased operating time due to the accumulation of OH^- ion accumulation in aqueous solution during the process. Depending on pH , metal ion generated by electrochemical dissolution of an expandable anode spontaneously undergo hydrolysis in H_2O. Adsorption and coagulation mainly depend on pH & additionally it influences the overall potency of electrocoagulation (Holt et al., 2006). Hence, the rise of pH is believed to ensure to the CO_2 unleash from hydrogen bubbling, because of the formation of precipitates of different anions with Al^{3+}, and because of the shift of equilibrium towards left for the H^+ unleash reactions. As for the pH decrease at alkaline conditions, it is due to the results of the formation of hydroxide precipitates with alternative Cations and therefore the formation of $Al(OH)_4^-$ as shown within the following equation (Chen et al., 2002):

$$Al(OH)_3 + OH^- \rightarrow Al(OH)_4^- \quad (5)$$

With pH increase, the speed of COD removal will increases since the impact of pH on coagulants depends on the produced reactions on totally different conditions.

In neutral conditions $$3Al_{(s)} + 8H_2O \rightarrow Al(OH)^+_{2(s)} + 2Al(OH)_3 + 4H_{2(g)} \quad (6)$$

In acid conditions $$2Al_{(s)} + 6H_2O \rightarrow O_{2(g)} + 4H_{2(g)} + 2Al(OH)_{2(s)} \quad (7)$$

In alkali conditions $$2Al(s) + 6H_2O \rightarrow 2Al(OH)_{3(s)} + 3H_{2(g)} \quad (8)$$

Here, $Al(OH)_2$ and $Al(OH)_3$ settle, while H_2 moves upward and causes flotation. As mentioned in the above reactions, associated acidity condition $Al\ (OH)_2$ and all alkali condition $Al(OH)_3$ are produced. Since $Al(OH)_3$ has higher weight and density, it settles quicker and has higher potency. Table 3 explains after doing ECC pH value increases from acidity to neutral.

Table 3: Effect of inter electrodes distance, electrolysis time and change in pH on pollutants removal efficiency in ECC process

S. No	Pollutant wastewater	Experimental setup	Initial pH	Final pH	ET (min)	Reference
1	Automobile garage wastewater	**Volume:** 2000ml **Electrode material:** Aluminum **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Parallel	5	7.06	14.6	Harinarayanan nampoothiri et al., (2015)
2	Synthetic Aqueous solution wastewater	**Volume:** 1000ml **Electrode material:** Aluminum **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Monopolar	4	8.5	30	Barun kumar nandi & sunil patel (2013)
3	Dairy wastewater	**Volume:** 1000ml **Electrode material:** aluminium **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Monopolar	7.10	8.54	60	Wael Qasim & A.V. Mane (2013)
4	Sweet-snacks wastewater	**Volume:** 1000ml **Electrode material:** Aluminum **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Monopolar	4.65	5.45	60	Wael Qasim & A.V. Mane (2013)
5	Ice-cream wastewater	**Volume:** 1000ml **Electrode material:** Aluminum **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Monopolar	6.11	6.35	60	Wael Qasim & A.V. Mane (2013)
6	Baker's yeast wastewater	**Volume:** 1000ml **Electrode material**: Al & Fe **Electrode arrangement:** Batch reactor **No of electrode:** 4 **Configuration:** Monopolar parallel	5.5	6.5	50	Kobya & delipinar (2008)
7	Dairy wastewater	**Volume:** 1000ml **Electrode material:** Fe **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Bipolar parallel	6	8	50	Kushwaha et al.,(2010)
8	Almond industry wastewater	**Volume:** 700ml **Electrode material:** Al & Fe **Electrode arrangement:** Batch reactor **No of electrode:** 2Al & 2Fe **Configuration:** Monopolar	5.7	7	30	David Valero et al., (2011)
9	Biodiesel wastewater	**Volume:** 500ml **Electrode material:** Al & graphite **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Monopolar	4	9	30	Orathai Chavalparit & Maneerat Ongwandee (2009)
10	Olive oil mill wastewater	**Volume:** 500ml **Electrode material:** Al & Fe **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** Monopolar	6.2	9	30	Inan et al., (2004)
11	Dairy wastewater	**Volume:** 1500ml **Electrode material:** Al **Electrode arrangement:** Batch reactor **No of electrode:** 4 **Configuration:** Bipolar	4.83	8	50	C. B. Jagadal et al., (2017)
12	Baker's yeast wastewater	**Volume:** 600ml **Electrode material:** Al **Electrode arrangement:** Batch reactor	4	6	20	Mohammad Al-Shannag et al.,

		No of electrode: 4 **Configuration:** Monopolar parallel				
13	Deinked tissue wastewater	**Volume:** 1000ml **Electrode material:** Fe **Electrode arrangement:** Batch reactor **No of electrode:** 6 **Configuration:** Monopolar	5.5	8.5	45	Shademan pourmousa (2017)
14	Fruit – juice production wastewater	**Volume:** 1000ml **Electrode material:** Fe & Al **Electrode arrangement:** Batch reactor **No of electrode:** 2 **Configuration:** monopolar	4.1	7.8	60	O. T. Can (2013)
15	Tunisian Industrial wastewater	**Volume:** 1000ml **Electrode material:** Al **Electrode arrangement:** Batch reactor **No of electrode:** 6 **Configuration:** Bipolar	2	10.9	30	Wided Bouguerra et al., (2015)

4.4 Effect of inter-electrode distance

It is one among the necessity factors influencing the electrocoagulation method. According to Ghosh et al. (2008), when the distance between the electrodes is less amount, then the attraction between the generated ions is additional, leading to the high movement of the ions. The generated ions endlessly continue colliding because of the supply of less area than the formation of flocs needed to coagulate the organic content. On additional increasing the gap between the electrodes beyond the optimum value, the quantity of anode dissolution decreases and therefore the ions have to be compelled to travel en extended distance for interaction to create the flocs. This can reduce the formation of flocs resulting in a reduction in the COD removal efficiency. Wherever COD decreases with the decrease in distance between electrodes Xu, et al. (2008). This is because the rate of electron transfer becomes quicker and therefore the shorter distance quickens the anion discharge on the anode and improves the oxidization. So, lesser distance spacing is more feasible for the removal of pollutant.

Energy consumption decreases with decreasing distance between electrodes, however, will increase the treatment potency, whereas increasing the electrodes spacing will reduce the cost of capital of treatment but may reduce the treatment efficiency.

4.5 Effect of operational time

Electrocoagulation "Time" is that the main parameter that includes a vital importance and influence on the performance of the ECC method. If retention time will increase with increasing removal potency. Removal potency directly proportions to time consumption. Treatment Time has a vital impact on the physical & chemical pollutants removal additionally it has vital improvement within the removal potency of the studied pollutants. If the time consumption is additional, the additional production rate of hydroxyl and metal ions on the electrodes that promotes a lot of removal potency of COD & color.

4.6 Effect of electrode material

The electrode assembly is that the heart of this treatment facility. So the suitable selection of its materials is extremely important because it affects markedly the performance of the electrocoagulation reactor.

4.7 Effect of the surface area to volume ratio (SA/V)

The surface area to volume ratio S/V is an extremely vital reactor design in ECC. S/V ratio, whose unit of measurement is known as m^1, is that the ratio of the active surface area of the quantity of the treated effluent. In step with the (Belhouta et al., 2010), the rise in the ratio S/V leads to the reduction of the current density consumption. Hence, it’s created necessarily to require into under consideration this parameter and verify its impact on the performance of the ECC method.

5. ARRANGEMENT OF ELECTRODE

In Electro coagulation the arrangement of the electrode can be done in the following three ways:

5.1 Monopolar electrodes in the parallel connections:

The monopolar electrode connected in the parallel arrangements is shown in figure 2.

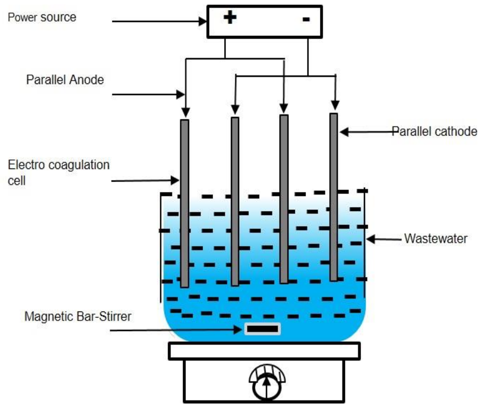

Fig. 2: Schematic diagram of Monopolar electrodes in the parallel connection.

An arrangement of Monopolar electrodes within the parallel connections is a simplest of an ECC cell. It primarily consists of pairs of semiconductive metal plates positioned in between 2 parallel electrodes and a dc power supply. During a monopolar arrangement, each pair of 'sacrificial electrode' is internally one another connected & additionally outer electrodes aren't interconnected. According to (Sandeep Thakur et al., 2016). Within the experimental set up a resistance box regulates the current density and a multimeter to read the current values. The semiconductive metal plates are typically known as 'sacrificial electrodes' which can be created of a similar or of dissimilar materials.

5.2 Monopolar electrodes in the series connections

The Monopolar electrode connected in the series arrangements is shown in figure 3.

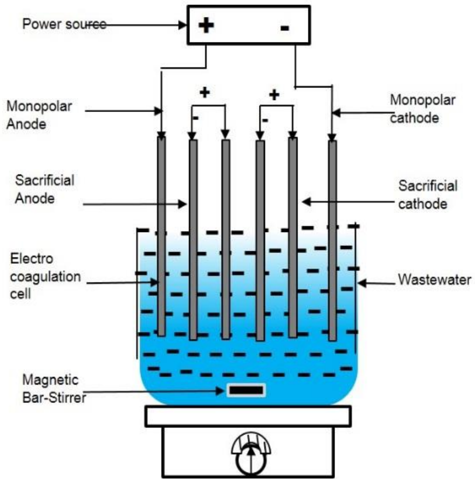

Fig. 3: Schematic diagram of Monopolar electrodes in series connections

An arrangement of ECC Cell provides a simple set-up. The sacrificial electrodes are placed between a pair of parallel electrodes with none electrical and solely 2 monopolar electrodes are connected to the power supply with none connections between the sacrificial electrodes that help in simple handling. As current is undergone the combination of electrodes, the neutral sides of the semi-conductive are going to be modified to charged face, that has opposite charge compared to the close parallel side. The sacrificial electrodes, in this case, also are known as bipolar electrode

5.3 Bipolar electrodes in the parallel connections

The bipolar electrode connected in the parallel arrangements is shown in figure 4.

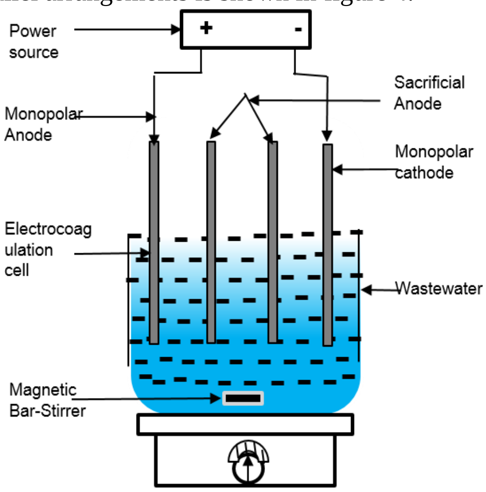

Fig. 4: Schematic diagram of bipolar electrodes in parallel connections

An arrangement of ECC cell provides an easy set-up that facilitates simple maintenance. During this arrangement, the sacrificial electrodes are positioned between the 2 parallel electrodes with none electrical connection, but a pair of monopolar electrodes are connected to the electrical power supply with none interconnections among the sacrificial electrodes. The neutral sides of the semi-conductive plate are going to be modified to charged sides once current is gone through the two electrodes. This side has opposite charge distinction to the corresponding side close to it. The sacrificial electrode during this situation is called bipolar electrodes (Pretorius et al., 1991) were ECC need simple equipment and is easy to operate. ECC cell has no moving parts and also the electrolytic processes are controlled electrically, therefore requiring less.

5.4 Effect of Shapes of the electrode

The shape of the electrodes is one of an important parameter, it affects the pollutant removal potency within the ECC method. Compared to plane electrodes, punched holes type electrodes can lead to higher removal potency. According to (Kuroda et al. 2003) higher discharge current for the electrode with punched holes than for plane electrode leading to higher assortment potency with punched electrode compared with the plane electrode. The electrical field intensity at the edge of punched holes type electrodes is higher (1.2 times) than at plane type electrode leading to arise within the discharge current at punched type electrode. Additional studies are required to determine the effect of the electrode shape (punched hole diameter and pitch of the holes) on the ECC method.

5.5 Effect of Conductivity

Conductivity is one of the very important parameters in the ECC process, wherever the removal potency of the pollutant and also operating cost are directly proportional to the conductivity. Energy consumption is also reduced with an increase in the conductivity

5.6 Effect of agitation speed

The agitation speed is one of an important parameter, it helps to maintain uniform conditions and avoids the formation of the concentration gradient within the ECC cell. Agitation speed directly proportional to pollutant removal potency. With a rise in the quality of generated ions, the flocs are shaped much earlier leading to arise within the pollutant removal potency for a specific electrolysis time. An additional increase in the agitation speed beyond the optimum value, there's a decrease in the pollutant removal potency because of high agitation speed flocs get degraded by collision with one another.

6. ADVANTAGES OF THE ECC PROCESS IN WASTEWATER TREATMENT

(Organization of American States. Water Reuse. Unit for Sustainable Development and Environment).

- ECC needs easy instrumentation and is simple to control with adequate operational latitude to handle most issues encountered on running.
- Processes Multiple Contaminants Simultaneously & Removes complex organics.
- Treating Wastewater by ECC provide tasteful, clear, colorless and odorless water.
- Removes heavy metals as oxides that pass toxicity characteristic leaching procedure (TCLP).
- Sludge formed by ECC tends to be promptly settable and easy to de-water, as a result of it's composed of primarily metallic oxides/hydroxides. Above all, it's a low sludge manufacturing technique.
- The ECC method has the advantage of removing the tiniest colloidal particles, as a result of the applied electric field sets them in quicker motion, thereby facilitating the coagulation.
- ECC method removes suspended, colloidal solids, Breaks oil emulsions in H_2O, Removes fats, oil, and grease & Removes complex organics.
- Flocs formed by ECC are like chemical floccule, except that ECC floccule tends to be a lot of larger, contains less bound water, is acid-resistant and a lot of stable, and thus, is separated quicker by filtration.
- The ECC method avoids uses of chemicals, and then there's no drawback of neutralizing excess chemicals and no risk of secondary pollution caused by chemical substances additional at high concentration as once chemical coagulation of effluent is employed.
- The gas bubbles created throughout electrolysis will carry the pollutant to the highest of the solution wherever it is a lot of simply focused, collected and removed.
- The ECC method is often handily employed in rural areas wherever electricity isn't accessible since a solar panel hooked up to the unit is also adequate to hold out the method.
- Operation and maintenance are comparatively easy except in direct recycle systems.
- Where more extensive technology and quality control are required.
- Destroys and removes bacteria, viruses, and cysts.
- Provision of nutrient-rich effluent will increase agricultural production in water-poor areas.
- One of the most Important advantages is Solar power can be used.

7. THE DISADVANTAGE OF ELECTRO-COAGULATION

- The sacrificial electrodes are dissolved into effluent streams as a result of oxidization and want to be frequently replaced.
- The use of electricity could also be costly in several places.
- A water-repellent oxide film is also formed on the cathode resulting in loss of potency of the ECC unit.
- The high conductivity of the effluent suspension is needed.

8. APPLICATION OF ELECTRO-COAGULATION

- Organics Removal, Phosphate & Nutrient Removal.
- Groundwater cleanup, Influent quality water control & Potable water.
- Sewage treatment, Cooling towers & radioactive isotope removal.
- Pretreatment with reverse osmosis, ultrafiltration, Nano filtration.
- Water utilizes leading to zero discharge, Metal recovery & Industrial waste water.
- Process rinse and wash water.

9. BENEFITS OF ELECTRO-COAGULATION

- Green and sustainable technology – eliminate chemicals
- Treat advanced waste streams
- Reclaim & harvest metals & oils
- Minimal chemical additions, meet discharge requirement & water recycling
- Supplied as a skid-mounted unit, fully assembled for inlet/outlet and backwash connections
- Low operating costs, Low power requirements, Low maintenance & Sludge minimization
- Reduce & process waste streams with multiple contaminants & ease of integration.

9.1 The electrocoagulation process has been successfully used to

- Harvest protein, fat, and fiber from food processor waste streams
- Recycle water, allowing closed loop systems.

- Remove metals and oil from wastewater.
- Recondition antifreeze by removing oil, dirt, and metals.
- Recondition brine chiller water by removing bacteria, fat, etc.
- Pretreatment before membrane technologies like reverse osmosis.
- Precondition boiler makeup water by removing silica, hardness, TSS, etc.
- Recondition boiler blow down by removing dissolved solids eliminating the need for boiler chemical treatment.
- Remove BOD, TSS, TDS, FOG, etc., from wastewater before disposal to POTW, thus reducing or eliminating discharge surcharges.
- De-water sewage sludge and stabilize heavy metals in sewage, lowering freight and allowing sludge to be land applied
- Condition and polish drinking water
- Remove chlorine and bacteria before water discharge or reuse

10. CONCLUSIONS

This paper has given a review of the successful electrocoagulation application, for the removal of mainly COD, BOD and color were this cannot be removed using conventional treatment method. By using electrocoagulation treatment method effectively we can remove COD, BOD & Colour. It is economical and environmentally friendly also environmentally sustainable. Now a day increasing water pollution one of the best method to reduce pollution is electrocoagulation & also electrocoagulation process effective in treating wastewater, parameter such as pH, current density, wastewater type, applied voltage, electrode material, electrolysis time, sample volume, electrode arrangement, no of electrode, size of electrode and inter-electrode distance as well as optimum removal efficiency used must be considered. Electrocoagulation has successfully for treating a polluted wastewater. But it not yet to be fully realized due to some deficiencies that are It requires more fundamental knowledge and optimized process for engineering design, no dominate reactor design exists, construction material may be varied & adequate scale up parameter have not been defined.

This technology will continue to make an inroad into the wastewater treatment because of its various advantages, capacity and strategic global needs.

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